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Research Article

Integrating EICAT and EICAT+ assessments and expert knowledge to classify invasive alien plants in France, based on their ecological impact

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Abstract

The EICAT and EICAT+ methods were developed to assess the negative and positive environmental impacts of alien species respectively. While both methods are theoretically applicable across spatial scales, their use has thus far been predominantly at the global level. In the case of EICAT, this reflects its original design for global assessments, whereas for EICAT+, which was only introduced in 2022, its application across different spatial scales remains to be assessed. At this stage, it remains unclear to what extent EICAT and EICAT+ can effectively support national regulations or local management strategies. Here we put forward a series of adaptations with the aim of enhancing the applicability of EICAT and EICAT+ at the national level. The main adaptation was to incorporate expert knowledge from botanists and wildlife specialists into the assessments, in addition to the literature review. To this end, a key was designed to facilitate the translation of field observations into impact categories using standardised criteria. We then tested the formal EICAT and EICAT+ protocols and EICAT and EICAT+ based protocols in France on 228 invasive alien plants. This test demonstrated that expert knowledge is an essential source of data for national-scale assessments, as it allowed reducing the proportion of Data deficient species from 39% to 5% for EICAT and from 86% to 37% for EICAT+. Consequently, this study represents the most thorough evaluation to date of the current ecological impacts of alien plants in France, highlighting 129 out of 228 taxa with harmful impacts: 71 taxa with a Moderate impact, 56 taxa with a Major impact and two taxa with a Massive impact. Furthermore, when using both EICAT and EICAT+, it is crucial to emphasise that directly comparing the two methods is not appropriate. National priority lists should be formulated solely based on EICAT, while EICAT+ can serve as a valuable tool for guiding managers on the risks associated with management actions and strategies to mitigate unintended consequences.

Key words: Environmental impacts, national assessments, positive impacts, priority lists

Introduction

Alien species introductions are increasing worldwide at an alarming rate, with no sign of saturation (Seebens et al. 2017). Amongst these introduced species, invasive alien species (IAS) have serious impacts on their recipient environments, including species extinction and irreversible changes to native ecosystems (Bellard et al.

2016; Doherty et al. 2016; Gallardo et al. 2016). Given their ever-growing numbers and the limited resources available for managing them, identifying the species with the most significant impacts is essential (Roy et al. 2015).

Dozens of methods have been developed to assess the environmental impact of IAS (Bartz and Kowarik 2019; Vilà et al. 2019). However, one method called Environmental Impact Classification of Alien Taxa (EICAT, Blackburn et al. (2014)) seems to have emerged in recent years as a standard for this purpose (Wilson et al. 2020), particularly after its adoption by the IUCN (IUCN 2020a) and its use in the recent IPBES IAS report (Bacher et al. 2024). EICAT provides a simple, standardised approach for classifying alien taxa based on the magnitude of their negative environmental impacts on native species populations in the recipient environment, considering both the reversibility of these impacts and the level of organisation affected (Blackburn et al. 2014; Hawkins et al. 2015). EICAT is composed of eight impact categories: Not Evaluated (NE), No Alien Populations (NA), Data Deficient (DD), Minimal Concern (MC), Minor (MN), Moderate (MO), Major (MR) and Massive (MV). It has been applied to a wide range of taxa from animals (Evans et al. 2016; Galanidi et al. 2018; Molfini et al. 2020; Allmert et al. 2022; Gruber et al. 2022; Clarke and McGeoch 2023) to plants (Visser et al. 2017; Canavan et al. 2019; Rockwell-Postel et al. 2020; Kendig et al. 2022), fungi and pathogens (Lapin et al. 2021). In addition to EICAT, a complementary method called EICAT+ was recently proposed to assess the positive environmental impacts of alien taxa (Vimercati et al. 2022). The categories of EICAT+ mirror those of EICAT and follow largely the same criteria. The combined application of EICAT and EICAT+ provides a comprehensive view of the ecological impacts of IAS.

The adoption of EICAT as an international standard facilitates comparisons between IAS impacts and may help to increase the consistency of national regulations (Kumschick et al. 2020a). However, questions remain about the potential of this method, as well as of EICAT+, for decision-making at the national scale. Most management strategies and regulation are developed at the national level, yet very few EICAT assessments at this scale are available to date. In theory, EICAT and EICAT+ can be used at any spatial scale (IUCN 2020a) even though they are primarily designed for global assessments, i.e. assessments of all the local impacts to define a category at a worldwide level. In practice, assessments strictly adhering to the protocols are almost always conducted at the continental or global scale (e.g. Canavan et al. (2019); Lapin et al. (2021); Allmert et al. (2022); Bescond-Michel et al. (2025)) and studies conducted at the national scale frequently involved a considerable number of taxa classified as Data Deficient (DD), which indicates a lack of sufficient data to assess their impact (see, for instance, Visser et al. (2017)). This issue arises from the limited availability of impact data to inform EICAT and EICAT+ assessments at a national scale. The protocols specify that only sourced data can be used (IUCN 2020a, 2020b), with both published (e.g. books, scientific articles) and unpublished (grey literature, reports, databases etc.) impact data being accepted. However, research on IAS is still limited and often focused on a few emblematic species, while comprehensive reports on the impacts of most IAS are lacking (Hulme et al. 2013). Furthermore, this issue is likely to be exacerbated when one wants to make EICAT or EICAT+ assessments at a reduced spatial scale in a given area.

The mismatch between the scale of global assessments and national plans is likely to hinder the use of EICAT and EICAT+ for decision-making and

national policy development. Global assessments are not always suitable for guiding national strategies, as the impacts they describe may have been measured under environmental conditions that differ significantly from those of the target region. As a result, their findings may not be directly applicable. For instance, the significant impacts caused by the tropical plant *Psidium cattleianum* in Mauritius island (Florens et al. 2017), are unlikely to occur in a temperate continental context. In some cases, however, global assessments, based on data from ecologically similar or geographically close countries, could be useful to determine potential impacts of these species in France. Nonetheless, relying too heavily on global assessments could lead to an overestimation of IAS impacts, increasing the risk of misdirected prevention and management efforts. Such cases may undermine the credibility of the assessments and provide arguments against the prevention, management or regulations of the IAS (Strubbe et al. 2019). Additionally, even global assessments may suffer from data deficiencies, as seen in several recent studies where over 90% of species were classified in the DD category (e.g. Swart (2017); Visser et al. (2017); Nurinsiyah and Hausdorf (2019)). These issues suggest that it might be useful to complete the EICAT protocol to enhance its applicability and allow the assessment of a greater number of species at reduced spatial scales.

Here, we propose several adaptations of EICAT and EICAT+ to enhance their suitability for national IAS management strategies. We tested the formal protocols and the adapted protocols at the national scale on a sample of 228 invasive alien plants (IAPs) known for their invasiveness in continental France and Corsica. Finally, we compared the outcomes of our assessments with the species listed under the Invasive Alien Species Regulation (EU Regulation 1143/2014), with the aim of exploring how EICAT-based evaluations could provide information, even indirectly, for the development of a national list of regulated species, as envisioned in Article 12.

Materials and methods

Taxa selection

For our test, we selected the main invasive alien plants (IAPs, specified below) in France. The taxa were identified on the basis of published regional lists of IAPs, which are available for all regions of France (references in Suppl. material 1: table S1). These lists are built by expert botanists from the National Botanical Conservatories, based on the observation data they centralise in their territory. On this basis, various risk assessment protocols have been applied to naturalised plants in the region - mainly the EPPO prioritisation process (Brunel et al. 2010; Branquart et al. 2016) and the Weber and Gut (2004) risk assessment - to generate prioritised lists for each region. From these regional lists, we selected plants from the highest risk categories (see Suppl. material 1: table S1 for the risk categories included). We excluded any taxa considered native in at least one part of France, even though they are alien and classified as invasive at the regional level. This resulted in a list of 202 taxa, with an additional 26 taxa included due to their recent emergence as invasive species — occurring after the publication of earlier regional lists. Finally, we obtained a list of 228 taxa that are supposed to have a high local impact on biodiversity.

The taxa were assessed at the species level, except for two taxa (*Lamium galeobdolon* subsp. *argentatum* and *Lapsana communis* subsp. *intermedia*) that were assessed at the subspecies level because at least one of their subspecies was native to France. We also assessed one taxon, *Phyllostachys*, at the genus level. This genus includes a large number of species and cultivars that are difficult to identify. Knowledge of *Phyllostachys* in France (and elsewhere in Europe) remains limited: although high impacts are regularly observed, the exact species involved is rarely identified (Brundu et al. 2025). To avoid producing mislabelled assessments with a low level of confidence, we preferred to treat *Phyllostachys* at the genus level, even though it is clear that not all species within this genus are naturalised or have a similar impact in France.

Implementation of the assessments

To assess the impact of invasive alien plants of France with an EICAT and EICAT+ based protocol, we created a three-step workflow (Fig. 1). Both negative and positive impacts assessments were conducted simultaneously.

Step 1: formal EICAT/EICAT+ assessments

The first step involved collating impact data from bibliographic sources and making a formal EICAT/EICAT+ assessment for each species (Fig. 1, step 1). We performed a comprehensive search of the published literature across the first ten pages of Google Scholar. The binomial names of the taxa were searched using additional key terms in both English and French: "France" and "naturalise" OR "envahissant" OR "invasive" OR "impact community" OR "hybridization" OR "introgression". To collect data from sources other than published academic articles, such as reports, websites and Master's or PhD theses, we also conducted a comprehensive search on the first ten pages of Google using the taxa names with the key terms "naturalise France" OR "envahissant France" OR "invasive France" OR "Natura 2000 France" OR "Réserve naturelle" OR "chantier gestion" OR "menace espèce en danger" OR "monospécifique" OR "suivi envahissante CBN" OR "suivi envahissante CEN". In addition, we gathered impact data from non-digitised French journals on plants and ecology. All documents were filtered to exclude impacts measured in countries other than France. Each impact data entry was then assessed following the EICAT and EICAT+ protocols: the type and magnitude of the impacts were scored, as well as the confidence in the impact assessment (Fig. 1, step 1).

One of the main constraints of EICAT and EICAT+ is that they only permit the use of data derived from published literature and observations (e.g. open databases or reports) and of impacts from the study territory, which are scarce for France. We believe it is possible to maintain a somehow objective, high-quality protocol while incorporating expert knowledge, provided that specific conditions, as detailed further, are met. In our assessments, expert knowledge was integrated in two ways. Firstly, by collecting unpublished field observations of inferred impacts from botanical and faunal experts across the country (Fig. 1, step 2). Secondly, through the consultation of a group of experts, whose role was to review the impact categories obtained, based on published literature (EICAT/EICAT+ assessments) and field observations (Fig. 1, step 3). These two steps were possible thanks to the involvement of a large number of experts coming from all over continental France and Corsica and who specialised in various fields (botany, phytosociology, invasion ecology, entomology, see Suppl. material 1).

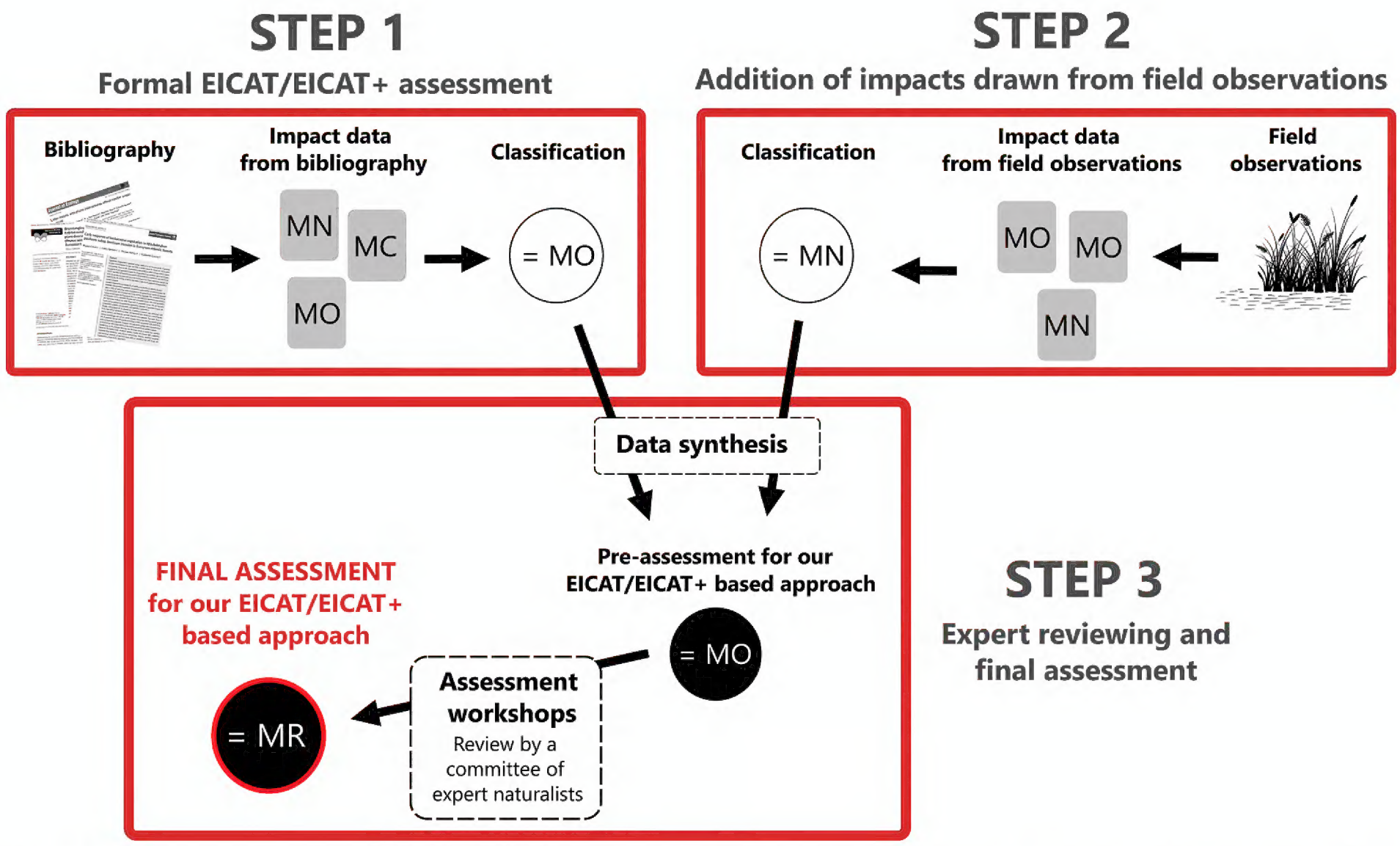

Figure 1. Workflow of the adapted EICAT and EICAT+ assessments performed at the national scale. Figure modified from Kumschick et al. (2020b).

Step 2: inferred impacts from unpublished field observations

The second step involved collecting field-based observations of inferred impacts from botanical and faunal experts across the country, using an analysis grid, based on EICAT/EICAT+ categories (Table 1). Forty-four experts and structures (naturalists and organisations specialising in biodiversity study and management) were contacted, but only 14 provided an assessment (the list of experts and structures involved in the assessments is provided in Suppl. material 1). The selection of experts and organisations contacted was made, based on their knowledge of the impact of IAPs or on their expertise on taxonomic groups potentially affected by IAPs. Experts were asked to assess all species according to EICAT and EICAT+ (Fig. 1, step 2), using a guide we provided that explained both methods and our adapted criteria for field data. To support consistent interpretation and minimise subjectivity, we translated the EICAT impact categories into observable, quantifiable field criteria (Table 1). Specifically, we used three simple indicators: plant cover, stand size and persistence of pressure over time. These were inspired by the EPPO prioritisation process (Brunel et al. 2010) and selected for their ease of assessment and relevance to local impacts on native species.

The assessments of unpublished field observations followed two rules. They were based on the maximum recorded impact observed by the assessor for the taxa (i.e. worst-case scenario amongst all inferred impacts detected), although we instructed assessors not to report outliers arising from abnormal situations (e.g. dense stands recorded immediately after an anthropogenic disturbance). Furthermore, the assessments of field observations were made at the scale of the site (typically between 10 m^2 and 10,000 m^2), a site being defined by a homogeneous area in terms of habitat or environmental conditions (soil type, vegetation, hydrology etc.).

Table 1. Criteria used to translate botanists' unpublished field observations of IAP cover, stand size and persistence into EICAT -based impact categories and confidence levels. All observed impacts were considered during the assessment. However, only the highest level of impact recorded by the assessor in the field was used to define the final impact category, following a worst-case scenario approach.

Parameters		Translation in field observation
EICAT-based impact categories	Data deficient (DD)	Alien plant rarely observed with no visible impact.
	Minimal concern (MC)	Alien plant regularly observed with no visible impact. The species never forms dense stands.
	Minor (MN)	Alien plant with sufficient development (cover and/or size) to limit the growth of other species, without causing an apparent decline of their population.
	Moderate (MO)	Alien plant that colonises areas of several tens to hundreds of m^2 with high coverage (> 50%), reducing the abundance or excluding at least one native species in these areas.
	Major (MR)	Alien plant that colonises areas of thousands of m^2 with high coverage (> 50%), with populations persisting on sites over time (at least 10 years) and that systematically excludes at least one native species.
	Massive (MV)	(i) Alien plant that has led to the local extinction of an isolated population of a native species (without possibility of re-colonisation) or (ii) alien plant that colonises areas of thousands of m^2 with high coverage (> 50%), with populations persisting on sites over time, that systematically excludes at least one native species and that has a long-term known abiotic impact.
Confidence score	Low	Possible impact: the impact is difficult to estimate (heterogeneous behaviour depending on the site, for example).
	Medium	Probable impact: for a species that often presents the same impact.
	High	Certain impact: for a species that almost always exhibits similar and clear impacts.

EICAT and EICAT+ focus on the impacts of IAS on local population dynamics. However, quantifying such effects using field observations is difficult, especially in a continental context where most native species are widely distributed and the size of their local populations is difficult to define. Here, we chose to assess the inferred impact of IAPs at the site scale, even though local native populations are likely to extend over larger areas than the sites. This decision was based on two arguments: (i) any scale size larger than a site cannot be easily assessed using field observations and (ii) the site scale is much larger than the size of the quadrats (i.e. a few square metres) that are commonly used to assess the impact of IAS in scientific studies. We also proposed a translation of the criteria used to assess confidence levels (see Table 1), as in EICAT, they focus on the characteristics of scientific studies and so could not be fully applied to field observations. For EICAT+, the translation of field observations could not be standardised. Synergistic interactions (e.g. via mutualism) or indirect interactions that lead to positive impacts are more difficult to unravel than antagonistic interactions (e.g. via competition), requiring more complex experiments - consequently, making the assessment of positive impacts by expert opinion difficult to standardise.

It should be noted that the formal EICAT/EICAT+ assessments based on published literature differed slightly from assessments based on unpublished field observations (see Fig. 1). While the bibliography allows assigning different impact categories according to the impact mechanisms (e.g. Major impact by competition, Minor by allelopathy, etc.), such precision cannot be achieved with field observations, as only the overall inferred impact of the IAPs is visible. For field observations, the assessment of impact categories was thus made at the taxon level for all mechanisms combined, without further distinction (e.g. Species A: Major impact by competition, allelopathy etc.).

In addition to the standard information recorded for the unpublished field observations (i.e. the type and magnitude of impacts and the confidence score), a brief paragraph describing the inferred impact was requested. This allowed the assessor to specify

details such as the size of the stands, the type of environment colonised, the names of native taxa impacted and the geographical area concerned by the assessment.

At the end of Step 2, we had both an impact category resulting from the strict application of EICAT and EICAT+ (Step 1) and an inferred impact score based on field observations (Step 2). A combined score from these two steps was proposed at this stage and will, hereafter, be referred to as the pre-assessment. The combined score was obtained by taking the highest impact category from formal EICAT/EICAT+ assessment and inferred impacts from field observations. This approach follows the maximum recorded impact precept of the EICAT/EICAT+ method.

In addition to the pre-assessment, this step also included supplementary information beyond the strict EICAT evaluation, such as the presence of the invasive species in Natura 2000 habitats and a list of threatened species affected by the IAPs assessed, using data collected from various sources, notably the French Red List (IUCN France et al. 2018, IUCN France et al. 2021). Impacts on habitats and species of concern (e.g. rare, threatened or heritage species) are often considered as a key information for prioritising IAS management and should, therefore, deserve to be included in impact assessments. Therefore, we used reports on the impacts of all focal IAPs on native threatened species and Natura 2000 habitats to facilitate the prioritisation of IAPs sharing the same EICAT and EICAT+ categories in any subsequent analyses. In EICAT, all impacted native species are given equal weight in the assessment, whether they are common or of conservation concern. Similarly, the presence of an invasive species in a ruderal habitat or in a habitat of community interest does not affect its impact level. Without altering the EICAT methodology, we believe that recording, in parallel, whether impacts involve heritage species or whether the invasive species occurs in priority habitats would allow for a more refined ranking of invasive plants within the same EICAT impact category. We recorded the names of all threatened species impacted by different IAPs, but we could not record the name of all Natura 2000 habitats impacted, because some IAPs occur in more than a dozen habitats (e.g. *Ailanthus altissima*, authors' personal observations) and it was sometimes difficult to precisely identify the impacted syntaxa. A native species was considered threatened if it were classified as "Vulnerable", "Endangered" and "Critically Endangered" in the IUCN Red List of France. The pre-assessments and associated information were all produced by one author (TDS).

Step 3: final assessment including expert consensus

The third and last step was to review the pre-assessments produced at the end of step 2. The final assessments were reached through seven half-day workshops, during which all the pre-assessments were reviewed by an independent committee (Fig. 1, step 3). The committee consisted of five to twelve botanical experts coming from all over France (see list of experts in Suppl. material 1). During the workshops, each of the pre-assessments was discussed and, if appropriate, modified in light of the experts' field experience and the available data.

Consensus amongst all experts present was required for any changes to the initial scoring to be adopted. This is a crucial aspect of our approach, as previous studies have demonstrated the potential for subjectivity in expert knowledge and the importance of peer review by a group of experts (Vanderhoeven et al. 2017; González-Moreno et al. 2019). As the experts participating in each workshop were different, a final round of discussion was held for all species with all experts to standardise the final impact categories.

Results

EICAT and EICAT+ formal assessments

A total of 549 distinct negative impact entries were identified for the EICAT assessments, based on 281 bibliographic sources (formal EICAT and EICAT+ assessments are available in Suppl. material 1: table S2). These negative impact entries concerned 139 alien plant taxa, with an average of 2.41 ± 3.80 (mean ± SD) impact data per taxon (n = 228). No negative impact data were found in the bibliography for 39% of the taxa (Fig. 2). The bibliography found provided little information for the EICAT+ assessments, with only 60 positive impact data entries from 42 bibliographic sources identified. The positive impacts concerned 33 alien taxa, with an average of 0.26 ± 0.73 data entry per taxon (n = 228). For 86% of the taxa, no positive impacts were found (Fig. 2). At this stage (EICAT/EICAT+ formal assessment), no alien plant species were classified within the highest impact categories, i.e. Massive (MV, indicating a naturally irreversible extinction of a native taxon) and Massive positive (MV+, signifying long-lasting re-establishment of a native taxon). However, all the other categories were attributed to at least one taxon.

EICAT-based and EICAT+ based assessments informed by field-inferred impacts

In total, 176 EICAT-based and 103 EICAT+ based assessments were drawn from unpublished field observations. Ninety-six taxa were concerned by the EICAT-based assessments (all the other were classified as DD), with an average of 0.77 ± 0.14 assessments per taxon (n = 228); while 71 taxa were concerned by the EICAT+ based assessments, with an average of 0.45 ± 0.81 assessments per taxon (n = 228). All impact categories, except Massive positive (MV+), were assigned during the EICAT+ based assessments drawn from unpublished field observations.

Addition of experts' knowledge

During the final assessments workshops, expert knowledge was also provided by a committee of botanical experts. The true contribution of expert knowledge can thus be evaluated by comparing the result of the EICAT/EICAT+ assessments with the bibliography and the final assessments with the EICAT/EICAT+ based approach. This comparison shows that expert knowledge was a crucial source of data in both the EICAT and EICAT+ assessments, significantly reducing the number of taxa classified as Data Deficient (DD). For EICAT, the proportion of taxa classified as DD decreased from 30% to 5% and for EICAT+, it decreased from 63% to 37% (Fig. 2). Expert knowledge also helped to refine the assessments of taxa with bibliographic data. For EICAT, considering expert knowledge resulted in an increase in the impact category for 40 taxa and a decrease in category for 37 taxa. Three species with bibliographic data were also classified as DD based on expert knowledge (*Cotoneaster divaricatus*, *Populus* × *canadensis* and *Nassella tenuissima*). For EICAT+, two taxa had their impact category increased, while six taxa had it decreased due to expert knowledge. One species with bibliographic data of positive impacts (*Carpobrotus acinaciformis*) was classified as DD, based on expert knowledge. The EICAT and EICAT+ impact categories assigned at each stage of the assessment process are available in Suppl. material 3.

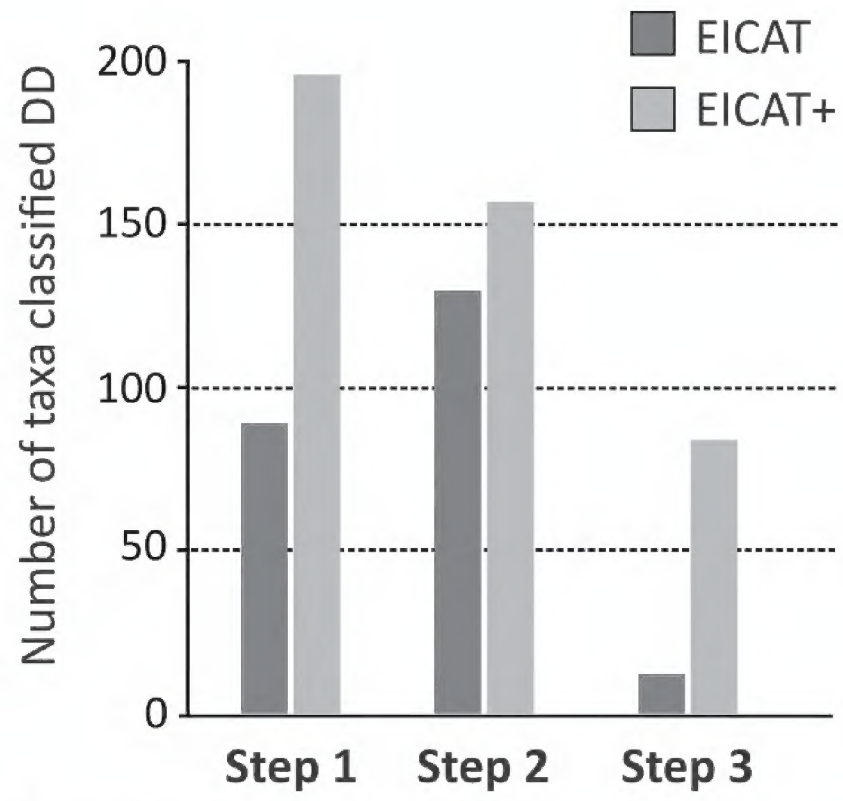

Figure 2. Number of taxa classified in the Data Deficient (DD) category at the different steps of the assessments (Step 1: formal EICAT/EICAT+ assessments ; Step 2: EICAT/EICAT+ based assessment, based on unpublished field observations of inferred impact ; Step 3: Final assessment including expert knowledge).

Results of the final EICAT and EICAT+ based assessments

Final EICAT and EICAT+ assessments are available in Suppl. material 4. Of the 228 taxa assessed, 216 (95%) and 144 (63%) were assigned to an impact category other than DD in the EICAT and EICAT+ based assessments, respectively. All impact categories were assigned at least once, except for MV+ (the highest EICAT+ category), which was not assigned to any taxon. Only two species, *Robinia pseudoacacia* and *Acacia dealbata*, were found to have a MV impact. Both species are known to alter plant communities and to cause the disappearance of populations of some native plant species. Their impact was judged irreversible due to the likely long-term increase in trophic level they cause on meso- and oligotrophic soils. The taxa classified in the MR or MV impact categories are listed in Table 2.

The comparison of EICAT and EICAT+ assessments revealed significant differences in the results. High impact categories are over-represented in EICAT compared to EICAT+ (Fig. 3). A total of 31% and 25% of the taxa were assigned to the MO and MR categories, respectively, whereas only 10% and 4% of the taxa were classified as Moderate positive (MO+) and Major positive (MR+). Moreover, fewer taxa were classified as DD in EICAT than in EICAT+ (12 vs. 84 taxa, respectively). The distribution of confidence levels of the two methods also differed, as the number of taxa with a low confidence level was less important for EICAT than for EICAT+ (70 vs. 108 taxa, Fig. 4).

The assessments showed marked differences depending on the type of native species impacted. A total of 79% of the EICAT assessments with a non-negligible impact (MN or greater) concerned flora exclusively, while 21% concerned both fauna and flora and no assessment concerned exclusively fauna. Conversely, the EICAT+ assessments focused mainly on positive impacts to native fauna: 74% of the assessments with a non-negligible impact (MN+ or greater) concerned exclusively fauna, while 16% concerned both fauna and flora and only 10% concerned only flora.

Table 2. Taxa name, impact category and impact mechanisms for the 58 IAPs classified in the Major and Massive categories during EICAT assessments. Taxa having negative impacts on threatened species are indicated with ●. Abbreviations: Comp = Competition; Chem = Chemical impact on ecosystems; Phy = Physical impact on ecosystems; Struc = Structural impact on ecosystems; Allelo = Allelopathy/toxicity; Hybrid = Hybridisation; Dis = Transmission of disease; Ind = Indirect impacts through interaction with other species; Others = All possible impact mechanisms other than those previously identified.

EICAT impact category	Taxa name	EICAT impact mechanisms
MV	*Acacia dealbata* ●	Comp, Chem, Struc, Ind
MV	*Robinia pseudoacacia* ●	Comp, Chem, Phy, Struc, Ind
MR	*Acer negundo* ●	Comp, Phy, Chem, Ind
MR	*Ailanthus altissima* ●	Comp, Allelo, Chem, Phy, Struc, Ind
MR	*Amorpha fruticosa*	Comp, Struc
MR	*Baccharis halimifolia* ●	Comp, Struc, Ind
MR	*Buddleja davidii* ●	Comp, Allelo, Phy, Struc, Ind
MR	*Cabomba caroliniana*	Comp
MR	*Carpobrotus acinaciformis* × *C. edulis* ●	Comp, Chem, Struc, Ind
MR	*Carpobrotus edulis* ●	Comp, Chem, Struc, Ind
MR	*Cenchrus clandestinus*	Comp
MR	*Cortaderia selloana* ●	Comp, Phy, Struc, Others, Ind
MR	*Crassula helmsii*	Comp, Phy, Chem, Struc
MR	*Delairea odorata*	Comp, Phy
MR	*Egeria densa*	Comp, Phy, Chem, Struc, Others
MR	*Elodea nuttallii* ●	Comp, Struc
MR	*Eragrostis curvula*	Comp, Phy, Struc
MR	*Euthamia graminifolia*	Comp
MR	*Heracleum mantegazzianum*	Comp, Phy
MR	*Humulus japonicus*	Comp, Phy, Struc, Ind
MR	*Hydrocotyle ranunculoides*	Comp, Chem, Phy, Struc
MR	*Impatiens glandulifera*	Comp, Phy, Ind, Allelo
MR	*Koenigia polystachya*	Comp, Ind
MR	*Lagarosiphon major*	Comp, Chem, Phy, Struc, Others
MR	*Ludwigia grandiflora* ●	Comp, Chem, Phy, Struc, Ind
MR	*Ludwigia peploides* ●	Comp, Chem, Phy, Struc, Ind
MR	*Medicago arborea*	Comp, Allelo, Struc
MR	*Myriophyllum aquaticum*	Comp, Chem, Phy, Struc, Ind
MR	*Parthenocissus inserta*	Comp, Phy, Struc, Ind
MR	*Paspalum distichum* ●	Comp, Ind
MR	*Paspalum paucispicatum*	Comp, Struc
MR	*Phyllostachys* (genus level)	Comp, Ind
MR	*Pistia stratiotes* ●	Comp, Phy
MR	*Prunus laurocerasus*	Comp, Allelo, Chem, Phy, Struc, Ind
MR	*Prunus serotina* ●	Comp, Chem, Phy
MR	*Quercus rubra*	Comp, Phy, Ind
MR	*Reynoutria japonica*	Comp, Allelo, Phy, Struc, Ind
MR	*Reynoutria* × *bohemica*	Comp, Allelo, Phy, Struc, Ind
MR	*Rhododendron ponticum*	Comp, Dis, Phy
MR	*Rudbeckia laciniata*	Comp, Struc
MR	*Rumex cristatus*	Comp, Hybrid, Struc

EICAT impact category	Taxa name	EICAT impact mechanisms
MR	*Sagittaria graminea* ●	Comp
MR	*Salvinia molesta*	Comp, Phy
MR	*Senecio angulatus*	Comp, Phy
MR	*Solidago canadensis* ●	Comp, Allelo, Ind, Struc, Phy
MR	*Solidago gigantea*	Comp, Allelo, Ind, Struc, Phy
MR	*Spiraea alba*	Comp, Allelo, Struc
MR	*Spiraea* × *billiardii*	Comp, Allelo, Struc
MR	*Sporobolus alterniflorus* ●	Comp, Phy, Chem, Struc
MR	*Sporobolus anglicus*	Comp, Phy, Chem, Struc
MR	*Sporobolus indicus*	Comp, Phy, Struc
MR	*Sporobolus pumilus* ●	Comp
MR	*Sporobolus* × *townsendii*	Others
MR	*Stenotaphrum secundatum*	Comp, Struc
MR	*Vallisneria australis*	Comp
MR	*Vitis acerifolia* × *Vitis riparia*	Comp, Phy
MR	*Vitis riparia*	Comp, Phy
MR	*Vitis riparia* × *Vitis rupestris*	Comp, Phy

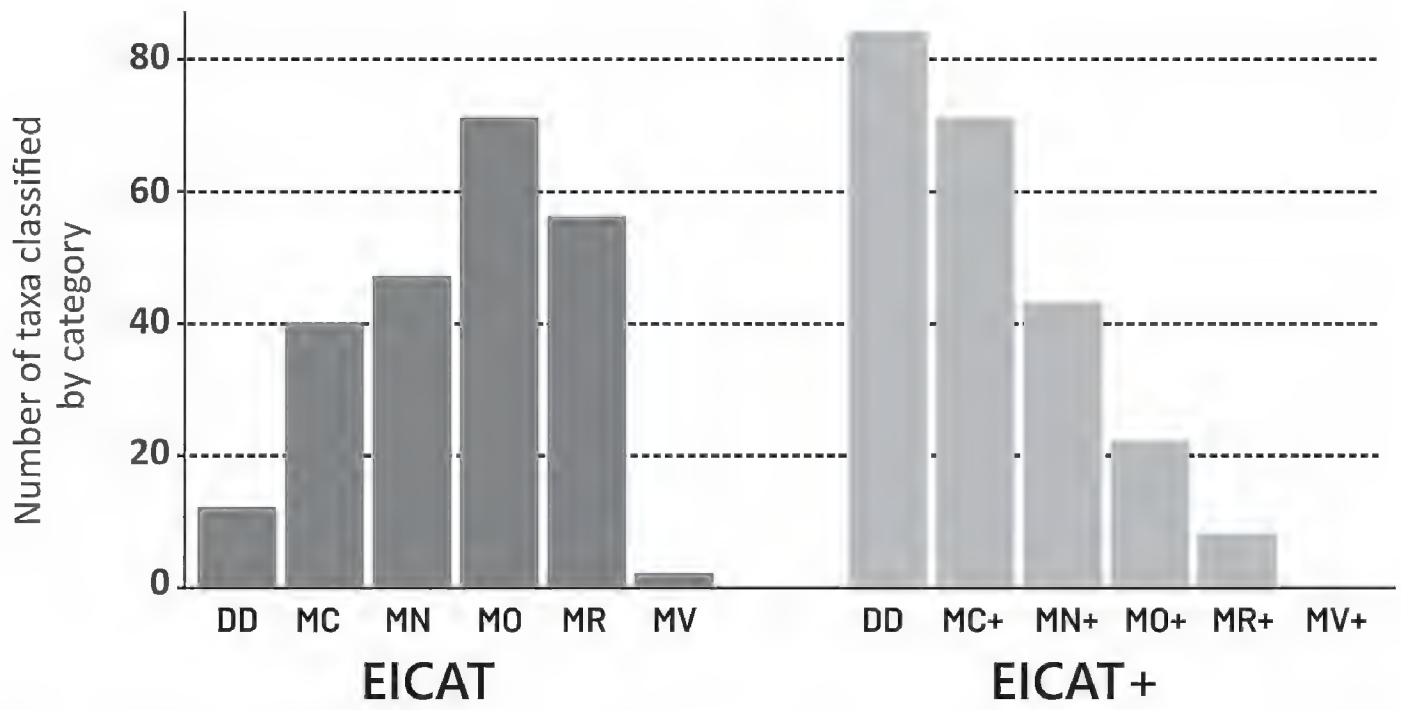

Figure 3. Number of taxa assessed by impact categories for the 228 main IAPs of France with the method EICAT and EICAT+.

Nine different impact mechanisms were assigned during EICAT assessments (Fig. 5). The most frequent negative impact mechanisms were Competition (212 alien taxa), Structural impacts on ecosystems (79 alien taxa), Physical impacts on ecosystems (58 alien taxa) and Indirect impacts through interaction with other species (44 alien taxa). In the EICAT+ assessments, eight different mechanisms were recorded (Fig. 5). The most frequent was the Provision of trophic resources (71 alien taxa), followed by Structural impacts on ecosystems (24 alien taxa). It should be noted that no mechanism could be attributed to a large number of taxa with a Minimal positive impact, because no positive impacts were reported in literature.

The results for the impacts on threatened species and Natura 2000 habitats were contrasted. Only 37 taxa were identified as having a negative impact on threatened species. This represented 29% of the high impact taxa (MO or above). The majority of these taxa were reported in bibliographic sources. The conservation status

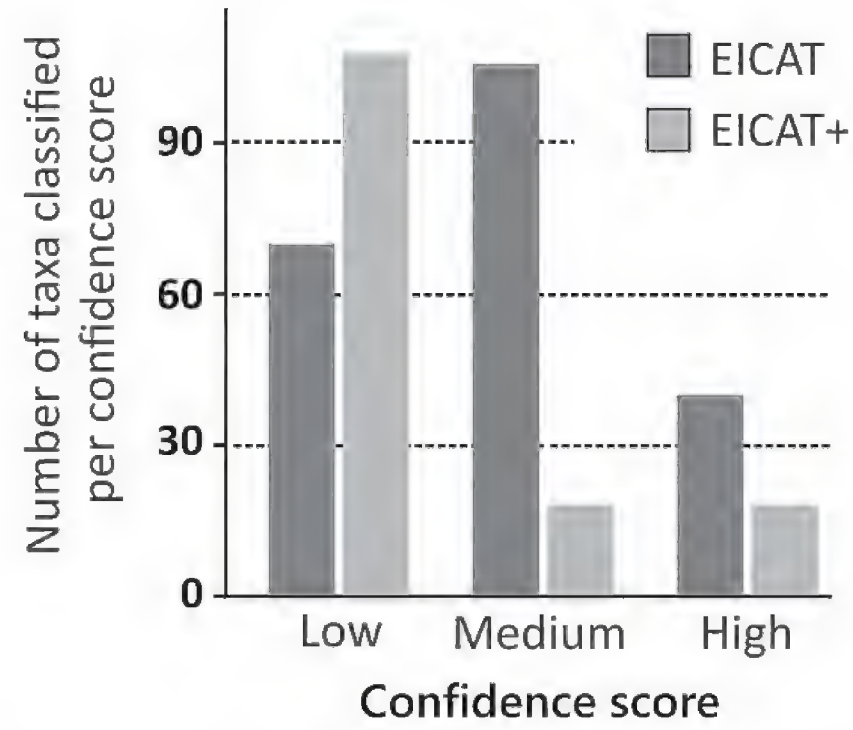

Figure 4. The percentage of the EICAT and EICAT+ assessments found per confidence score. Assessments were carried out at the scale of France on 228 invasive alien plants.

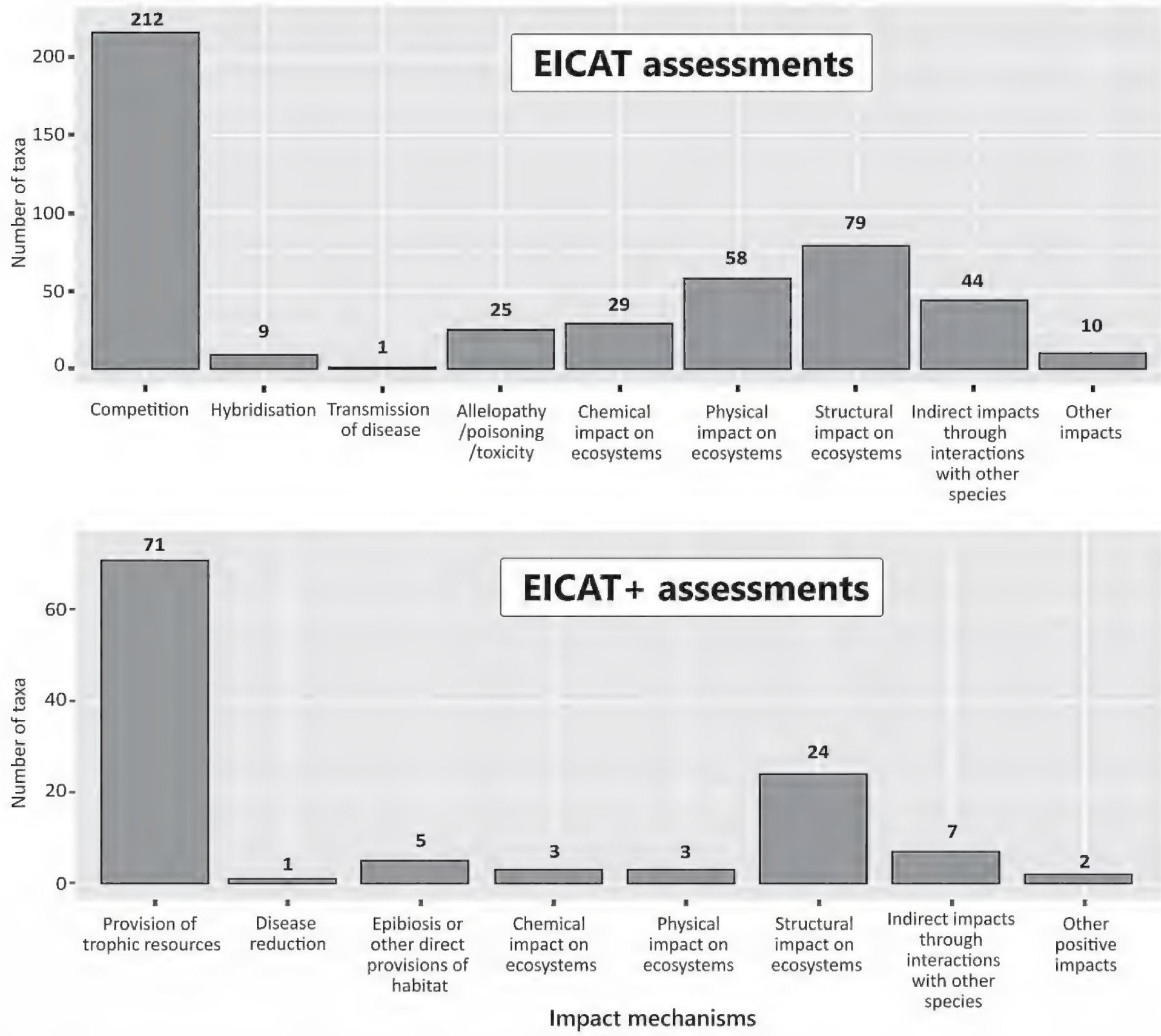

Figure 5. The number of taxa assigned per impact mechanism during the EICAT and EICAT+ assessments. Assessments were carried out at the scale of France on 228 invasive alien plants. In some cases, several mechanisms have been attributed to the same taxa, while no mechanism could be attributed in other cases (mechanism unknown or impact too low for a mechanism to be attributed). Note that each plot employs distinct y-axis ranges.

of threatened species impacted by IAP varied largely ranging from Vulnerable to Critically Endangered and belonged to various groups (e.g. plants, fish, reptiles, molluscs etc.). Additionally, eight IAPs were identified as having a positive impact on threatened species, six of which were aquatic plants that formed large meadows providing hunting and nesting areas for pike (*Esox lucius*, assessed as Vulnerable in the French Red List). On the other hand, impacts on Natura 2000 habitats have been reported for 95 taxa, which represented more than 74% of taxa with a strong impact (MO or above). The vast majority of the impacts on Natura 2000 habitats have been identified according to expert observations.

Focus on the EU IAS Regulation assessed

Amongst the 41 plant taxa listed in the EU IAS Regulation by December 2024, 21 were assessed in our study (Suppl. material 5). Almost all of them were given a harmful impact: fifteen were classified in the MR category and five in the MO category. Only one species, *Lysichiton americanus*, was classified in the MN category. No species was classified in either the MC or MV impact category.

Discussion

In this study, we proposed a protocol, based on the EICAT and EICAT+ methods to facilitate their use at a national scale and on plant species. We then applied these EICAT and EICAT+ based protocols in France, on the 228 main invasive alien plants of the country. The results demonstrate that the adapted protocols can be effectively implemented at the national level with relatively low to moderate rates of taxa classified as data deficient (5% for EICAT and 37% for EICAT+). However, this work also revealed that EICAT and EICAT+ protocols should not be applied together to make national priority lists.

We proposed to integrate supplementary information to EICAT and EICAT+ methods: (i) the integration of expert knowledge as a source of information for inferred impact data in a highly structured way to limit subjectivity and (ii) the consideration of impacts on species and habitats of concern. The former can be considered essential if national assessments are to be carried out. Indeed, expert knowledge not only significantly reduced the number of Data Deficient species, but also enabled the improvement of assessments for taxa with existing bibliographic data. Given the number of taxa lacking bibliographic information — 31% for EICAT and 86% for EICAT+ — our work shows that it is probably very hard to apply these methods at a national scale without considering expert knowledge. This type of information source had already been used in previous adapted EICAT assessments (Borroto-Páez et al. 2015; Booy 2019; Molfini et al. 2020; Bueno et al. 2021; Dehnen-Schmutz et al. 2022). However, the aforementioned works did not provide clear criteria defining how unpublished field observations could be considered in the assessments. The challenge in defining certain concepts in a practical term, particularly that of a local population, raises concerns about the reproducibility of these assessments. It is our hope that the quantifiable and observable criteria we have proposed will prove useful in this regard. The criteria are based on the size of the stands and on the local impact observed within the stands. Since IAPs usually form dense, monospecific stands over large areas and are highly conspicuous in the field, these criteria are easy to assess, especially when an IAP has a significant pressure. This characteristic is

valuable, as it simplifies the assessment of the inferred impacts of the invasive alien plants compared to those of invasive alien animals.

Conversely, the practicality of our second complement remains questionable. As previously reported in other European countries (Lazzaro et al. 2015; Rabitsch et al. 2020; Misuri et al. 2024), our assessments have shown that many IAPs have an impact on threatened native species and on Natura 2000 habitats in France. However, these data cannot be easily exploited for the creation of national priority lists or management strategies. The precise effects on threatened species in France remain insufficiently documented. There is a clear lack of evidence demonstrating a clear causal link between the presence of an IAP and the disappearance of threatened species from one or more sites. Almost no monitoring programmes have been conducted on the subject (but see Quéré (2010)), literature is scarce and sometimes unreliable and it is often difficult to detect such impacts using punctual unpublished field observations. On the other hand, the identification of IAPs having an impact on Natura 2000 habitats is much better known, thanks to the Natura 2000 network. Even so, the fact that highest impact taxa (MO or higher) also affected Natura 2000 habitats limits the relevance of this criterion for further prioritising species. Given these limitations, we recommend using only the EICAT impact categories to prioritise the IAPs, without currently relying on data regarding species or habitats of concern. Nonetheless, improving knowledge of the impacts on threatened species remains valuable, as this information could be used to establish conservation plans, in order to determine the IAPS concerned by management.

A good agreement was found between our EICAT assessments and the EU regulation on IAS even though assessments are not totally comparable because EICAT are only impact assessments whereas EU assessments are full risk assessments. Nearly all the 21 plant species that were both assessed here and that are in the list of Union concern of the EU IAS regulation were classified in the MO or MR category. The only exception was *Lysichiton americanus*, which was assigned in the MN category because its impacts are currently limited in France, maybe due to the frequent management of its populations. Nevertheless, this assessment aligns with the "Minor to Moderate" impact identified in the EPPO Pest Risk Analysis, which led to the inclusion of *L. americanus* in the EU's list of species of concern.

Moreover, even though a verification of the requirements of the Articles 4 and 5 of the EU IAS Regulation still remains necessary to include the species to the Union list, the fact that 43 out of the 58 taxa (74%) in the MR and MV category remain unregulated raises questions. While some species do not meet the criteria for inclusion (e.g. *Robinia pseudoacacia*, due to its economic interests), others would deserve to be added (*Senecio angulatus*, *Delairea odorata* etc.). Despite recent updates to the 'Invasive Alien Species of Union Concern' list in 2017, 2019 and 2022, further efforts are needed to improve the coverage of this regulation.

We found a strong imbalance between the taxonomic groups affected by the negative and positive impacts: negative impacts predominantly affected native plants, while positive impacts were more commonly observed in native animals. This may be explained by the fact that native flora is often directly threatened by alien plants, through competition for space, light, moisture or nutrients (Iponga et al. 2008; Bennett et al. 2011; Broadbent et al. 2018). In contrast, a more mixed response is expected for native fauna. The proliferation of IAPs is predicted to result in the decline of animals which are dependent on the impacted native plants, but it may also benefit some generalist species and the fauna dependent of the IAPs

(Carvalheiro et al. 2010; Harvey et al. 2010; de Araújo et al. 2015; Rodríguez et al. 2021). Furthermore, most IAPs are of horticultural origin (Reichard and White 2001; van Kleunen et al. 2018) and have been selected to produce large quantities of flowers or fruits, which can serve as trophic resources for animals. However, these resources are not always accessible to native fauna due to the lack of co-evolution with the alien plant. For instance, native herbivores may be unable to consume alien plants because of their naivety in face of novel chemical defences (Sedio et al. 2020). Further research is required to assess the generality of this asymmetry in impacts across taxonomic groups.

Expert knowledge, while beneficial in assessments, has notable limitations. Not all of the criteria used in EICAT and EICAT+ assessments can be easily evaluated through field observations. For example, effects on the performance of native species typically require testing under controlled conditions to be assessed (e.g. Bousquet-Mélou et al. (2005); Dandelot et al. (2008)). Likewise, several impact mechanisms, such as hybridisation or disease transmission, cannot be adequately assessed through field observations alone. In addition, expert knowledge may be difficult to handle, especially when discrepancies arise between field observations and the existing literature. Such instances were frequent in our assessment, but occurred mostly for taxa with unreviewed literature. In these cases, the final impact category was assigned after discussion amongst assessors, taking into account the level of confidence in field observations, bibliographic sources and the overall consistency of the evidence. If consensus could not be reached, additional independent experts were consulted.

The only case of a discrepancy between published literature and expert knowledge occurred for *Impatiens balfourii*. The species was reported to reduce the abundance of geophytes plants (MO impact) in a study conducted in southern France in the early 2010s (Fried et al. 2014). However, the species was subsequently assessed by experts as having negligible impact (MC). After discussion with one of the authors of the study, it was decided to adhere to the expert opinion. This decision was based on the fact that the study had investigated the impact of the invasive species only within their respective stands, without accounting for the reduced size of these stands, which typically measured only a few square metres. Furthermore, a study currently in progress, which involves re-measuring the impact of the species after approximately ten years, indicates that *Impatiens balfourii* has naturally disappeared from numerous quadrats where it was previously invasive. This observation reflects the ephemeral nature of its local impact (Fried, pers. obs.), thereby justifying the MC category.

Another limit of our study is the relatively low robustness of the assessment of IAPs' positive impacts. EICAT+ assessments included a large number of Data Deficient taxa (84 taxa classified DD) and a high proportion (75%) of assessments had a low confidence level. The main factor responsible for this pattern is the scarcity of available data. The positive impacts of IAS are a relatively new topic in invasion biology (Rodriguez 2006; Gribben et al. 2013; McLaughlan et al. 2014) and are currently less frequently studied and/or reported than negative impacts in scientific literature (Bacher et al. 2024). Two additional factors may also contribute to this pattern. First, most of the positive impacts that we detected were low, especially when compared to the negative impacts and weaker impacts are inherently more difficult to detect than stronger ones. Second, it is possible that the experts selected for the assessments were not the most qualified to assess the positive impacts, since

most of them were botanists and the majority of the positive impacts concern animals. Including fauna specialists is thus mandatory for accurate assessment of positive impacts, even if it may be difficult to involve experts that have both a good knowledge on fauna and are able to identify the IAPs.

Conclusion

Here, we presented an adapted version of EICAT and EICAT+ methods for assessing the ecological impacts of IAPs at the national scale. Our findings underscore the value of expert knowledge as an additional source of data at this scale. Conversely, the second inclusion we proposed — the consideration of impact on species and habitat of concern — did not prove relevant for prioritising the IAPs, at least with the currently available data in France.

In light of our findings, we advocate for a generalised and standard use of adapted protocols, based on EICAT for the national assessment of IAS impacts, in the same way that the Red List is used to assess threatened species. Such standardisation would allow for comparisons of observed impacts across countries. Previous studies have demonstrated that impacts observed under similar eco-climatic conditions are amongst the most accurate predictors of an exotic species' potential impact in a new environment (Grosholz and Ruiz 1996; Ricciardi 2003; Kulhanek et al. 2011). Consequently, the EICAT impact categories could not only be used to prioritise established alien taxa, but also to predict the potential impacts of species not yet introduced.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Use of AI

No use of AI was reported.

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Author contributions

A.A. and G.F. developed the research approach. All authors participated in the methodological work and the impact assessments. All authors contributed significant portions of original text to the manuscript and all authors edited and provided comments on manuscript drafts.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Name of the experts involved in the assessments, with the name of the structures to which the experts belong between brackets

Authors: Thomas de Solan, Guillaume Fried, Aurélien Caillon, Yohann Soubeyran, Arnaud Albert

Data type: docx

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Link: https://doi.org/10.3897/neobiota.105.144928.suppl1

Supplementary material 2

References for the French regional lists of invasive alien plants of France, with the name of the risk categories selected for assessment in our study

Authors: Thomas de Solan, Guillaume Fried, Aurélien Caillon, Yohann Soubeyran, Arnaud Albert

Data type: xlsx

Explanation note: The priority list for the Hauts-de-France region was not published and it was obtained directly from the Conservatoire Botanique National of Bailleul.

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Supplementary material 3

EICAT and EICAT+ categories obtained for the 228 invasive alien plants at the different stages of the assessment

Authors: Thomas de Solan, Guillaume Fried, Aurélien Caillon, Yohann Soubeyran, Arnaud Albert

Data type: xlsx

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Supplementary material 4

EICAT and EICAT+ assessements for the 228 main invasive alien plants of France

Authors: Thomas de Solan, Guillaume Fried, Aurélien Caillon, Yohann Soubeyran, Arnaud Albert

Data type: xlsx

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Supplementary material 5

EICAT impact category obtained from national assessments in France for the 41 plants recognized of Union concern by EU regulation

Authors: Thomas de Solan, Guillaume Fried, Aurélien Caillon, Yohann Soubeyran, Arnaud Albert

Data type: xlsx

Explanation note: Blanks correspond to species whose impact was not assessed in this study.

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